# *Lawrence Livermore National Laboratory / Energy Security and Technology Program*

*Jeffrey Stewart*

*Group Leader: Applied Statistics and Economics*

DOE Hydrogen, Fuel Cells, and Infrastructure Technologies Program

Systems Analysis Workshop

July 28-29, 2004

Washington, D.C.

# Charter

- *LLNL's mission is to provide research in the areas of national and homeland security and other important areas to DOE such as Energy,Climate and Water*
- *To conduct systems and economic modeling and analysis to determine the technical and economic characteristics of individual technologies **within** systems to achieve policy objectives*
- *DOE NETL, NE,Policy,HEU; Japanese Govt, CEC, Internal*

# History

- *LLNL has had a systems analysis group for over 25 years supporting national security, defense, energy and environment programs*
- *Developed a long term simulation model of the weapons stockpile stewardship program capturing research, production facilities, research facilities, expertise and budgets*
- *Conducted hydrogen analyses since early '90's. Studied transportation, storage technologies, and remote power systems, as well as overall energy system impacts.*

# Energy Technology and Security Program (ETSP)

**Program Staff**

Denise Falls
Helen Magann
Lilian Decman – Resource Manager
Sharice Tippens – Resource Manager

**Program Leader**
Ray Smith

**Deputy Program Leader**
John Ziagos

Systems & Decision Sciences Section, Engineering

**Energy and Technology Modeling**

Jeff Stewart, Group Leader
Alan Lamont, Senior Energy Modeler

## Energy Efficiency and Renewable Energy

Salvador Aceves
**Associate Program Leader**

- **Hydrogen Projects, Bob Glass**
- **Geothermal, Carol Bruton**
- **Renewables, Dora Yen Nakafuji**
- **Combustion, Salvador Aceves**
- **Materials**
- **Aerodynamics, Rose McCallen**
- **Magnetic Levitation & Bearings, Dick Post**

## Fossil Energy

Rick Blake
**Associate Program Leader**

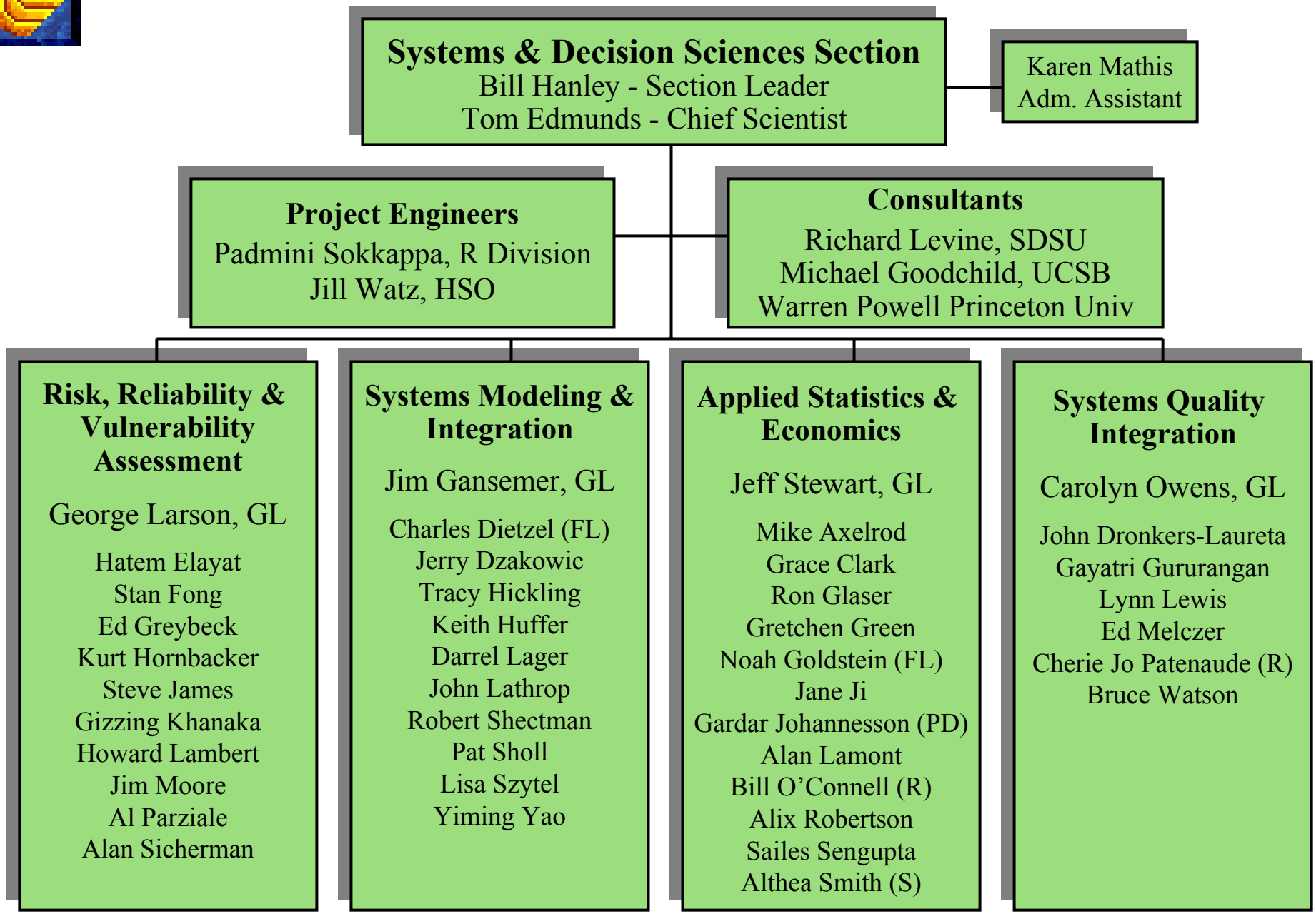
- **Vision 21, Rick Blake**
- **Enhanced Oil Recovery, Jim Johnson**
- **Gas Hydrates, Bill Durham**
- **NGOTP, Rick Blake**
- **Exploration Tools, Barry Kirkendall**
- **Natural Gas Infrastructure, Bill Pickles**

## Nuclear Energy

Ray Smith **(Acting)**
**Associate Program Leader**

- **NERI,**
- **Highly Enriched Uranium, Guy Armantrout**
- **$S^2TAR$**
- **GEN IV, AAA, and AFCI, Bill Halsey**
- **7 Lab**

7/19/04




R = Retiree; PD = Postdoctoral; FL = Fellowship; S = Summer Hire

# Skill Set - People

| Names | Skill Set |
|---|---|
| 1) Jeffrey Stewart | Economist |
| 2) Alan Lamont | Senior energy economist and systems analyst, |
| 3) Gene Berry | Material scientist and $H_2$ systems analyst |
| 4)Bill Daley | M. E, and programmer |
| 5)Alix Robertson, | Energy and environmental economics and ME, |
| 6)Gardar Johannesson | Spatial Statistics |
| 7)Tony Wu | Optimization modeling |
| 8)Noah Goldstein | Quantitative Geography |
| 9)Jill Watz | System and Chemical Engineering, Power Systems Engineering and Electric Power Deregulation, Policy and Economics |
| 10)Tom Edmunds | Optimization |
| 11)Gretchen Green | Applied Math,Visualization and programming |
| 12)Salvador Aceves | $H_2$ Storage |
| 13)Ray Smith | $H_2$ Combustion |
| 14)Robert Glass | $H_2$ production |

# Skill Set – Models

**(add slides as necessary)**

- *Models that explicitly include hydrogen*
  - *Meta-Net hydrogen production and storage system model (see attached slide)*
  - *Non-linear optimization based on market equilibrium*
  - *In current formulation only includes small set of primary technologies*
  - *Simultaneously optimizes system structure and operation based on sequential hour-by-hour modeling*
  - *Can be readily expanded*
- *Models that could be adapted to include hydrogen*
  - *META•Net Modeling system (Discussed in following slides)*
  - *Two versions: long-term and "hour-by-Hour"*
    - *Long term version models evolution of energy system based on market equilibrium accounting for changes in demands, resource exhaustion, introduction of new technologies, …*
    - *Hour-by-hour version models details of technologies operation and interaction. Optimizes operation and capacities of technologies to accurately economics of technologies* ***operating within a system***
  - *Modeling methodology: non-linear optimization*
  - *Model platform: META•Net is a modeling platform*
  - *Model limitations: Like other continuous function systems it cannot easily handle integer problems and non-convexities, hour-by-hour version takes time to converge*

# Skill Set – Capabilities Summary

**(Refer to $H_2$ Analysis Types – last Slide)**

| TYPE OF ANALYSIS | RESIDENT CAPABILITY? | STUDIES SPECIFIC TO $H_2$? | MODELS SPECIFIC TO $H_2$? |
|---|---|---|---|
| **Resource Analysis** | *Yes* | *No* | *No* |
| **Technoeconomic Analysis** | *Yes* | *Yes* | *No* |
| **Environmental Analysis** | *Yes* | *Yes* | *Yes* |
| **Delivery Analysis** | *Yes* | *Yes* | *No* |
| **Infrastructure Development Analysis** | *Yes* | *Yes* | *Yes* |
| **Energy Market Analysis** | *Yes* | *Yes* | *Yes* |

# Studies

- *Past studies related to hydrogen*
  - *Berry and Lamont:* Carbonless Transportation and Energy Storage in Future Energy Systems*.
    - Examined changes in energy system cost and structure as carbon eliminated and $H_2$ introduced; using hour-by-hour version of META•Net modeling system
  - *Comparison of $H_2$ production costs using a) dedicated renewable electric generation and b) renewable generation integrated into electric grid*
- *Past studies that could be adapted to hydrogen*
- *Remote Power Systems with advanced storage technologies for Alaskan Villages , Meta Net Energy Economic modeling system*

* In *Innovative Energy Strategies for CO2 Stabilization* (R. Watts, ed.) pp. 181-210. Cambridge University Press

# Studies

- *Past studies related to hydrogen*
  - *Thermodynamics of Insulated Pressure Vessels for Vehicular Hydrogen Storage.*
  - *Hydrogen Transportation and Storage in Engineered Glass Microspheres*
  - *Hydrogen as a Transportation Fuel: Costs and Benefits*
  - *Encyclopedia of Energy, Volume 3 (Chapters on both Hydrogen Production and Hydrogen Storage Technologies*
- *Past studies adaptable to hydrogen*
  - *Economic penetration of intermittent generation based on hour-by-hour modeling*

* In *Innovative Energy Strategies for CO2 Stabilization* (R. Watts, ed.) pp. 181-210. Cambridge University Press

# Future

- *The System and Decision Sciences Section has plans to add 15 people to the current staff of 45 researchers. Spatial Statistics,Visualization (including GIS) Economics and Optimization are some of the areas targeted for expansions.*

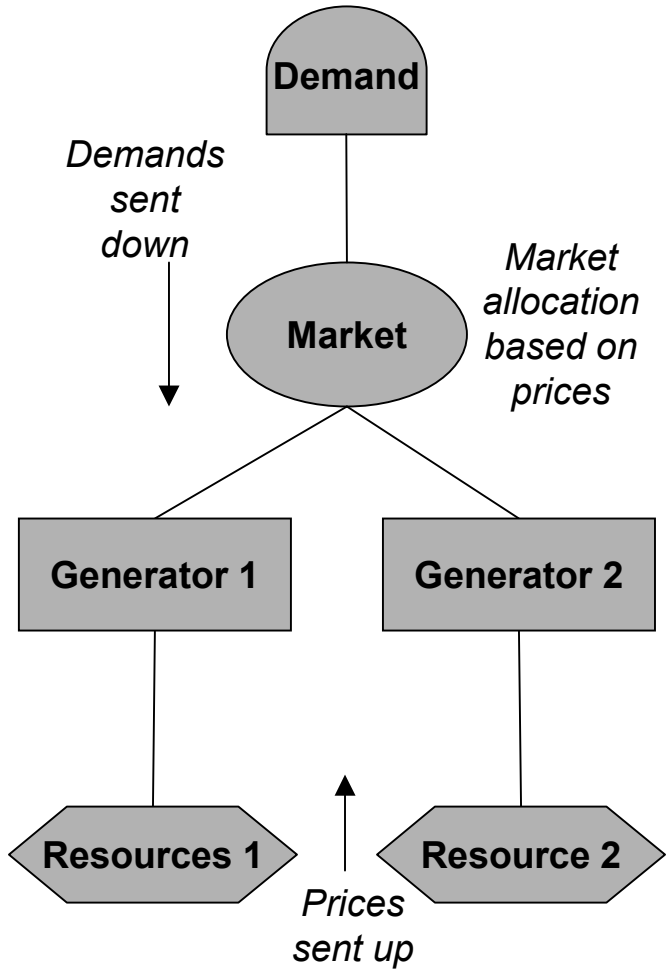
# Analysis Issues

- *Open podium – Major issues related to analysis of hydrogen systems?*
  - *Understanding the actual operation of $H_2$ production technologies and their integration with rest of system. In any situation where there is connection to the electric grid (electrolysis, joint production of electricity and $H_2$) hour-by-hour considerations and storage economics are important.*
  - *Should we start from desirable future scenarios or goals and model back to the present?*
  - *How to model the value of the strategic and operational stability a $H_2$ transportation sector offers future energy systems?*

# Backup Slides

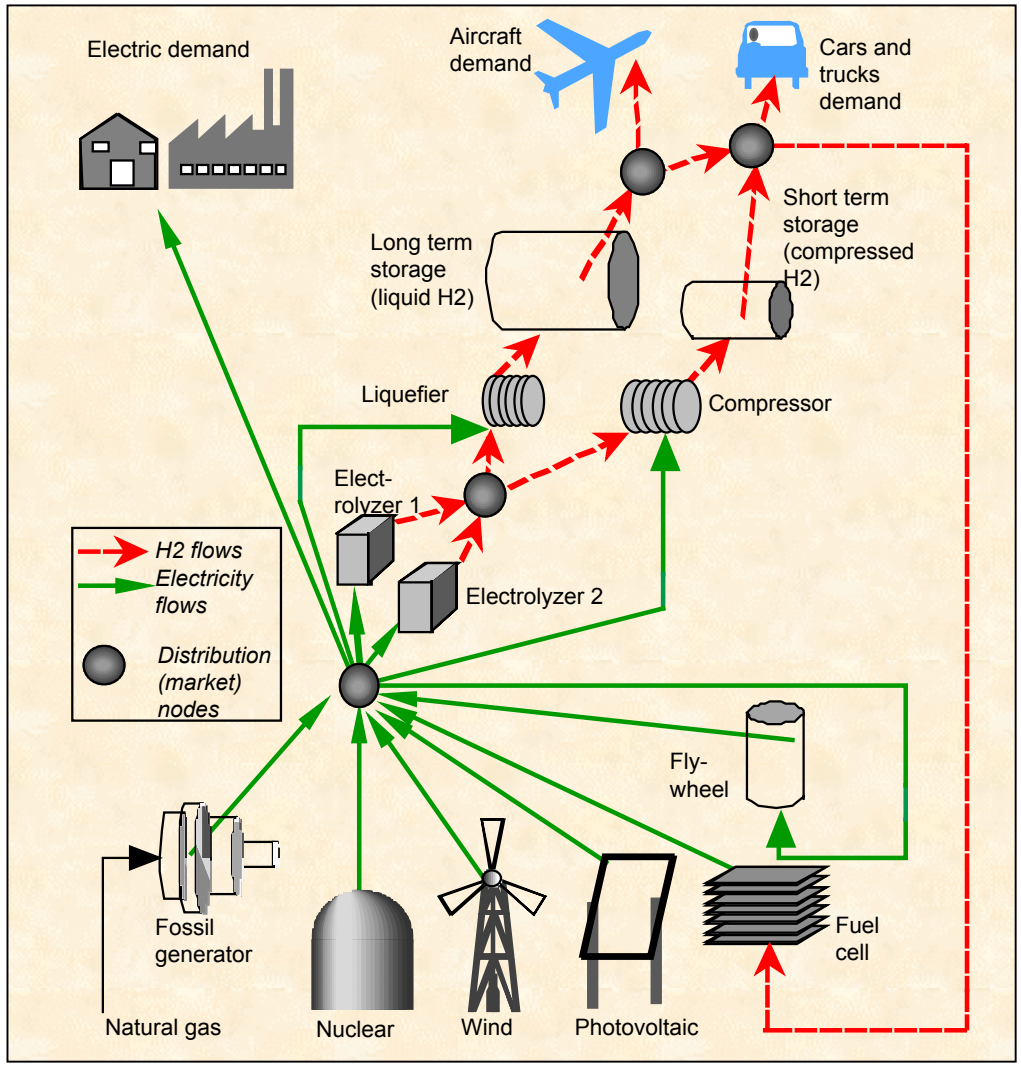
# LLNL energy modeling approach based on "network" approach

- Model consists of a network of nodes representing
  - End-uses (demands)
  - Conversions (e.g. coal into electricity)
  - Resources
  - Markets
- The model mimics a market equilibrium
  - Nodes exchange prices and quantities
  - Adjusts to reach equilibrium
- Equilibrium is equivalent to a cost minimizing optimum
- Two types of models
  - Long-term: evolution of energy system over multiple years
  - "hour-by-hour": optimal structuring and operation of system incorporating intermittents, storage, demand response



# Example of hour-by-hour $H_2$ production and storage model

- Understanding the change in the structure of the energy system as carbon emissions are reduced *at minimum cost*
  - Over a series of model runs, the allowable carbon was reduced to zero
  - Model finds the optimal *structure and hourly operation* of the system for each level of carbon emissions

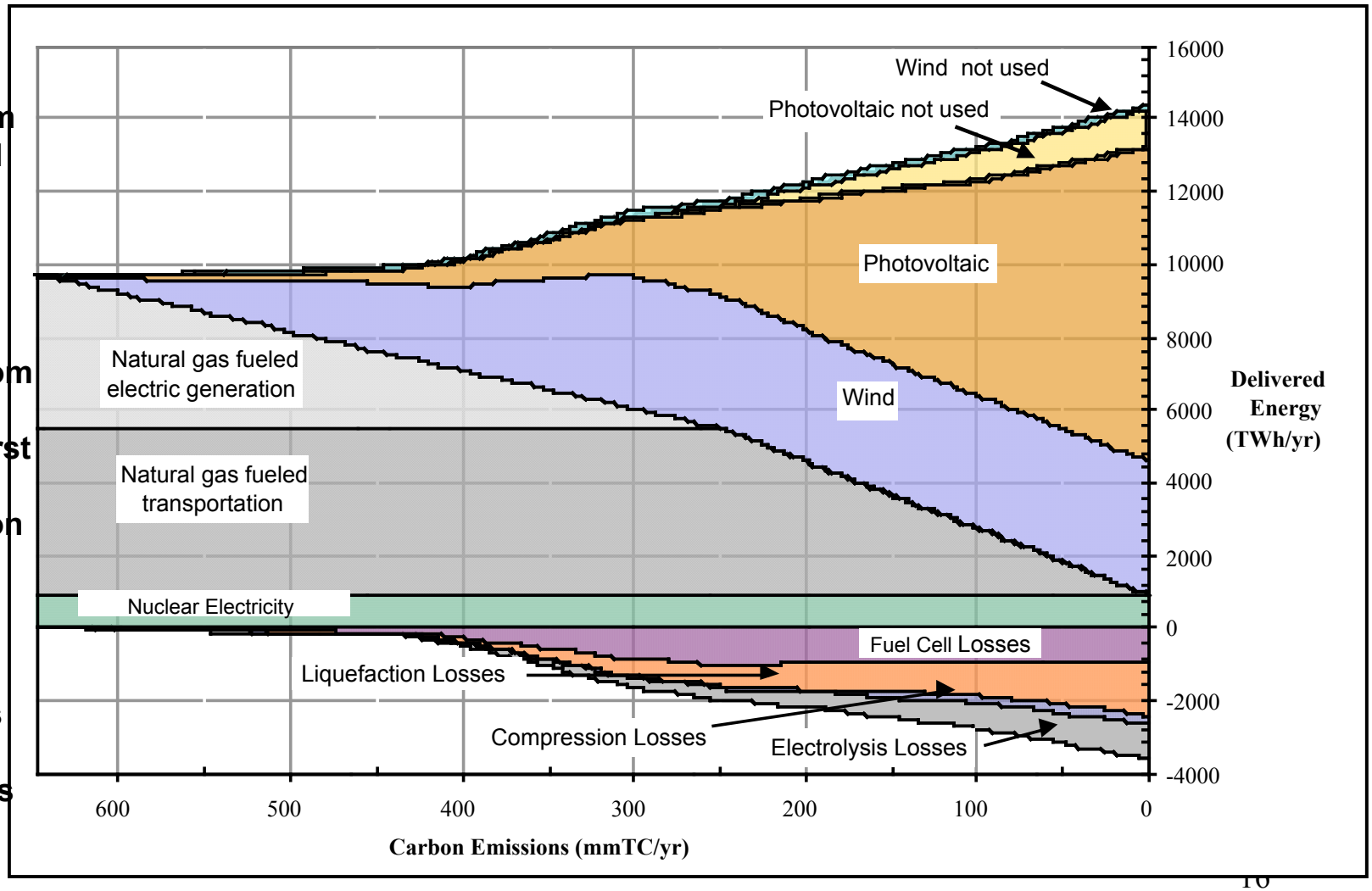


# Energy flows as carbon emissions are reduced

**Starting from efficient, all natural gas system**

**Reduce emissions from electric generation first and transportation second**

**Some PV is introduced although it is high cost**

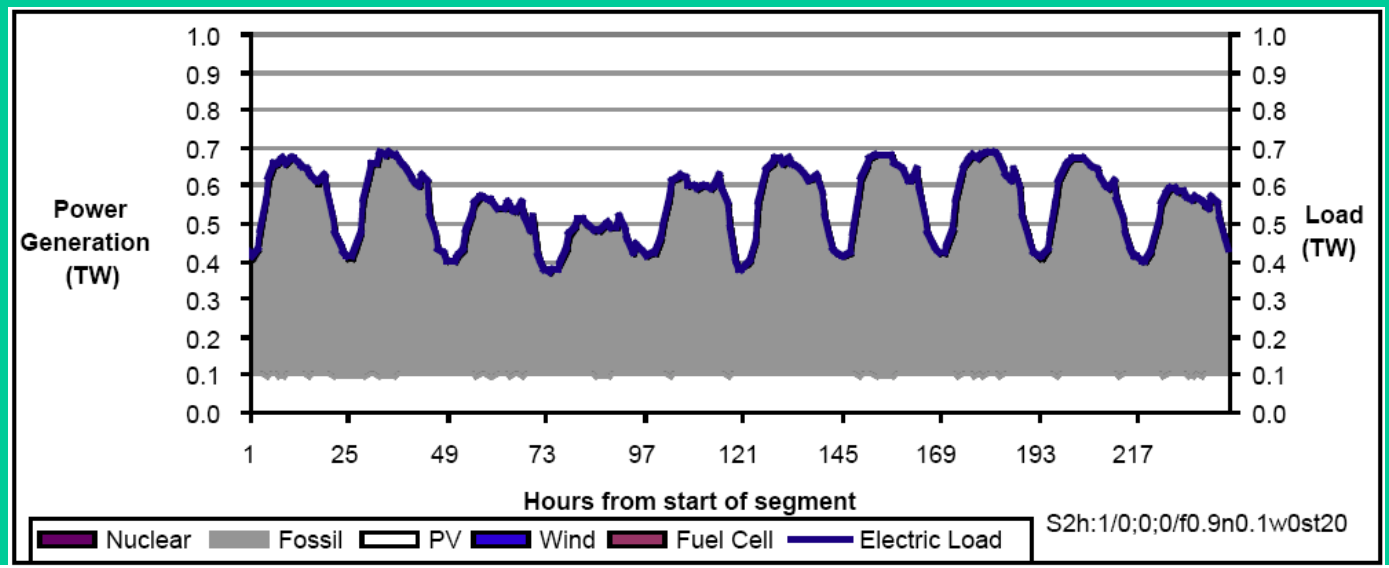




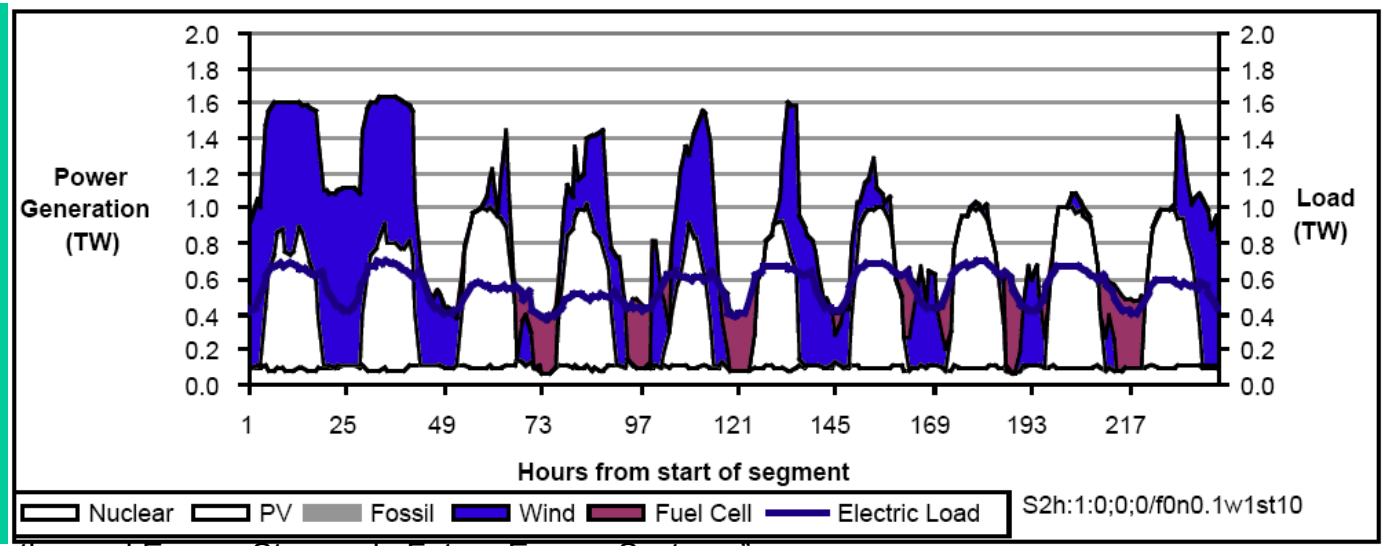

*from* "Carbonless Transportation and Energy Storage in Future Energy Systems"

# Examples of the hourly operation

**No carbon constraints**



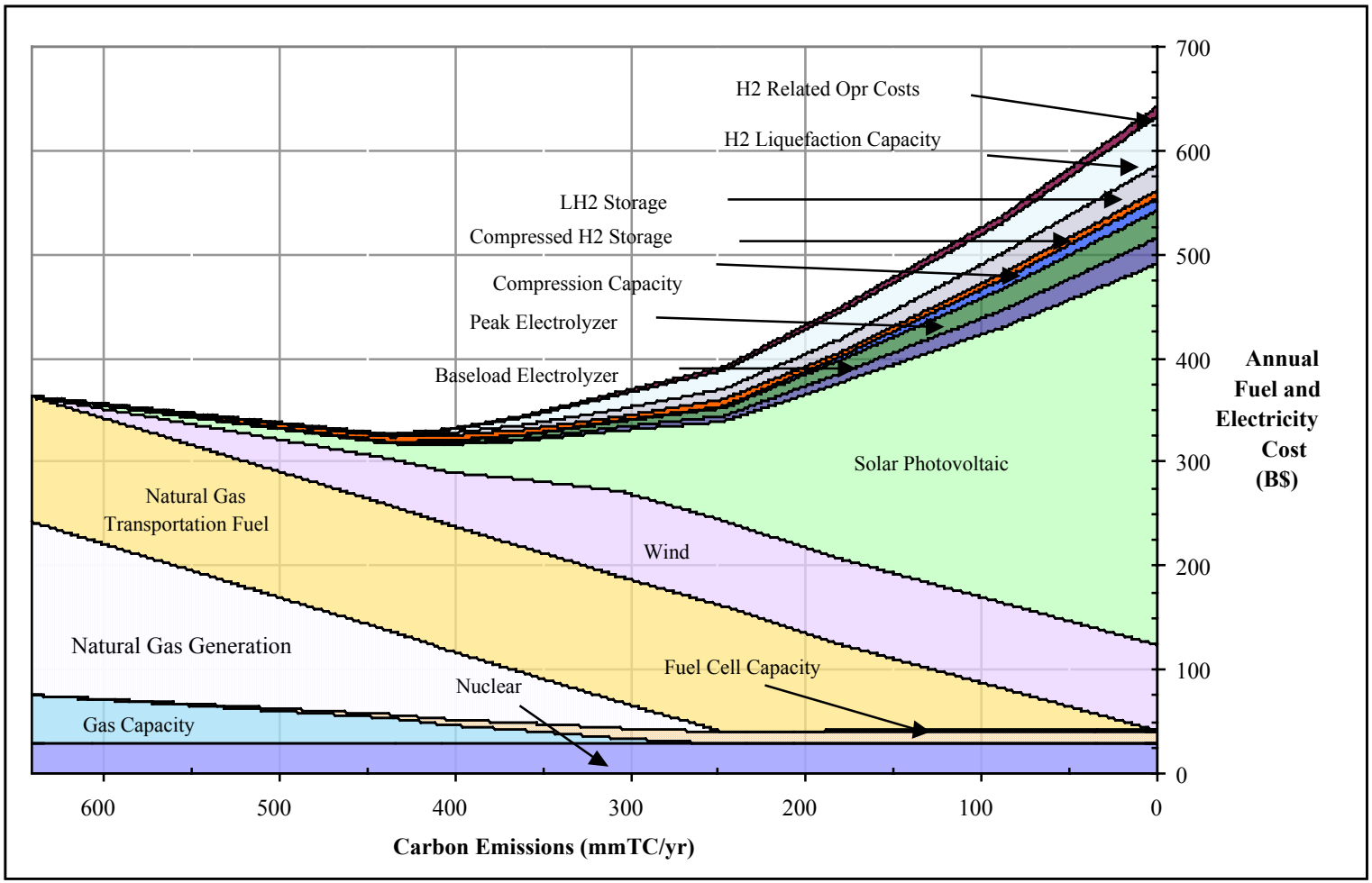

**Heavy carbon constraints**




*from* "Carbonless Transportation and Energy Storage in Future Energy Systems"

# Cost structure of systems as carbon emissions are reduced

**Cost of primary generation (eg PV) is most important, not other infrastructure**



# Types of Hydrogen Analysis

**Resource Analysis**
–Where are the resources to make hydrogen and how much do they cost?

**Technology Feasibility and Cost Analysis**
–Which technologies have the greatest potential for economic success?
–Where should research efforts be focused?
–What are the impacts of production volume?

**Environmental Analysis**
–What are the environmental impacts of hydrogen technologies?
–What steps can be taken to reduce impacts?

**Delivery Analysis**
–What are the most economic options for delivering hydrogen?

**Infrastructure Development and Financial Analysis**
–What are the optimal scenarios for developing the hydrogen infrastructure?
–What will a hydrogen infrastructure cost and what are the financial risks?

**Energy Market Analysis**
–What are feasible hydrogen futures?
–Which technologies are most likely to be a part of the hydrogen future, and what are the interactions between hydrogen and other energy carriers?
–What are the scenarios for hydrogen use in transportation and stationary markets?
–What are the impacts, costs, and financial risks?
–What market penetration pathways are likely?